https://rijournals.com/biological-and-applied-science/

RESEARCH INVENTION JOURNAL OF BIOLOGICAL AND APPLIED SCIENCES 5(1):67-70, 2025

©RIJBAS Publications ISSN: 1597-2879

https://doi.org/10.59298/RIJBAS/2025/516770

The Role of Digital Twins in Personalizing Patient Treatment Plans in Healthcare

Kibibi Muthoni L.

Faculty of Science and Technology Kampala International University Uganda

ABSTRACT

Digital twins, virtual replicas of physical entities or processes, have emerged as transformative tools in healthcare, offering unprecedented opportunities for personalizing patient treatment plans. By integrating real-time patient data with predictive models, digital twins enable healthcare providers to simulate outcomes, optimize interventions, and align treatment strategies with individual patient needs. This paper investigates the foundational concept of digital twins, their benefits in creating personalized treatment plans, and the technological infrastructure required for their implementation. It also examines ethical challenges and governance issues related to patient data, algorithmic biases, and decision-making. Furthermore, the discussion highlights future opportunities, including the integration of AI and machine learning to enhance digital twin systems. By addressing current limitations and ethical considerations, digital twins have the potential to revolutionize healthcare delivery, reduce costs, and improve patient outcomes on a global scale.

Keywords: Digital twins, personalized medicine, healthcare technology, predictive modeling, real-time patient data.

INTRODUCTION

Digital twins are virtual representations of physical objects or processes that offer the possibility of modeling and analyzing the current state of individual patient health or health delivery systems and simulating likely outcomes of potential interventions. Digital twins are a relatively new development in healthcare; this concept has existed in areas such as manufacturing and engineering for some time. As a scientific concept, the digital twin is relatively new and describes a virtual representation of a physical object or process, including associated predictions, testing, and what-if scenario development. It consists of a model of the entity and a real-time monitoring component, which links virtual and physical systems [1, 2]. A digital twin consists of a model of the entity and a real-time monitoring agent that brings the data from the physical entity into the model engine in real time. A digital twin reads all data with information flowing into the digital model. The data is then analyzed by the model, and the results drive predictions about things such as how the individual will react to different treatments or lifestyle changes. It can then be used to do predictive modeling based on historical data and current monitoring. Medical doctors can intervene at different decision points based on different outcomes, taking into account a patient's goals and values. To act on the twin's diagnoses is to act on knowledge about the likely outcomes [3, 4].

Benefits of Personalized Treatment Plans

The developed treatments and interventions can be tailored to fit the exact physiology and preferences of the patient. Consequently, the treatment or intervention can align with the patient's goals and preferences, ultimately improving the likelihood of a successful outcome. A variety of inputs are used, such as genetic, environmental, lifestyle factors, and diagnostic tests, to develop personalized treatment plans. As a result, whether it is determining which preventive screening test an individual may benefit from or determining which medication an individual may be more likely to respond to, personalization is expected to capitalize on the unique physiology and preferences of each patient. By doing so, this is expected to improve treatment efficiency as well as the likelihood of success. Clinical studies have provided evidence that personalized medicine initiatives have been successfully implemented across a wide range of health disorders and diverse populations. The anticipated benefits of personalization of therapy include lower costs, improved patient adherence, superior patient outcomes, and a higher likelihood of patient satisfaction. One of the potential advantages of genetic testing may be the testing for variants that may increase the likelihood of adverse drug reactions. If the drug is known not to be effective, in addition to avoiding adverse drug reactions, personalized treatment strategies can help decrease the cost of medication by reducing trial and error. Overall, the major goal of personalizing treatments is to produce a positive health outcome for the patient while providing a high level of patient satisfaction [5, 6].

Implementation of Digital Twins in Healthcare

For the practical implementation of digital twins in healthcare, it is important to have a strong technological infrastructure. This infrastructure should have the capability for continuous data collection from sources inside and outside of clinical settings. The data collected is then used in the real-time tracking, monitoring, and analysis of activities. Tools such as the integration engine and business intelligence software are used for continuous and near real-time patient data collection and subsequent analysis. The technological setup includes end-to-end data tracking and an intelligent surveillance system with high computational analytics capabilities, but it should also involve the role of data scientists who know how to handle big data with a level of knowledge of security and privacy issues related to patient data according to expected rules and regulations [7, 8]. It also includes a significant change in the way that operational IT professionals carry out their day-to-day work. It is important to train or at least provide active change management for the clinical as well as IT staff who have to deal with the issues or rather are the backend for these implementations. Implementing digital twin technology solutions can enhance the ability to understand the complexity of an illness or behavior that is being monitored using various types of data along with the integration of genetic data. Integration of sensor or imaging data under 3D-based analysis involves different levels of steps to be implemented as part of their processes. Another level of complex integration involves semantic interoperability based on standardization by integrating standardized disease identification codes to convert natural text from electronic health records to machine-readable codes as per agreed intelligent definitions that can be recognized by the digital twin. The perturbations workflow functionalities analyze any discrepancies that could happen in the knowledge-sharing domain of clinical expertise or expert system outputs, aiding the identification of tumor types, either benign or cancerous, among the population in a cost-effective manner. Interoperability in healthcare is still a significant challenge as there are few semantic constraints within the interactions of the entities. The idea of using a digital twin is still growing in healthcare, but there is much anticipation in the cycle of the cultures and strategies of its particular applications. The potential areas of the twin within optimizing patient care are currently a priority [9, 10].

Challenges and Ethical Considerations

In digital twins, the focus has currently shifted from data analysis and visualization to decision-making and design activities. These approaches build upon real-time measurement systems, artificial intelligence, and big data storage technologies where therapeutic command and control options are enabled through data assimilation of patient data. Yet, there are limitations to these improvements, such as ethics and governance issues associated with the use of medical data and making assessments and decisions that operate through digital entities. Additionally, the unregulated application of digital twin data can lead to incorrect diagnoses, suboptimal healthcare, and an increased amount of research data in the future [11, 12]. The IoT and digital twin approach provide a wide selection of data for individualized customized therapy planning if integrated into the electronic healthcare record and can feature improved insight for linking genetics and genomics data. Trusting an algorithm will remain difficult due to the representability of patient data and is currently the focus of extensive research efforts in computer science. Biases in algorithms can result from the lack of representability of vital signs gathered or demographic disparities. Ethical concerns are related to the use of personal data to facilitate digital twins and for what purpose. As most of the data are collected during a hospital checkup, in general, consent from the patient for further research or therapies is necessary. The ethics of creating digital models of patients for individualized care has been the focus of two perspectives presented. The ethics of withholding care has also been discussed. Limits, rules, and guidelines need to be set up for the decision-making algorithms running on newly obtained data. Balancing innovation and ethical obligations is essential, as a complete stop of all attempts will slow processes down and could reduce model predictions. Public engagement in tool development and transparency must be established to create trust in the new tools. A structured debate forum should be created to define guidelines and a regulatory framework for the use of new technologies, including digital twins. Social benefits might be used as incentives to share information. Support of additional social benefits can provide incentives for sharing information [13, 14].

Future Directions and Opportunities

While the digital twin is still in its infancy, several future trajectories and opportunities could galvanize its adoption in the healthcare domain. Technological advancements in image processing and predictive algorithms could potentially lead to more accurate simulations of disease progression. Furthermore, the advent and increasing affordability of in silico clinical trials, which utilize patient-specific digital twins to simulate the effect of various drug protocols or therapies, could be a major game changer for patient healthcare. The impending collaboration of other technologies, including AI, machine learning, and big data analytics, in combination with digital twin systems is anticipated to deliver faster, cheaper, and more accurate predictions and provide hidden insights into the causes and effects of healthcare scenarios. Synergetic efforts by clinicians, technologists, healthcare providers, and stakeholders could maximize the gain from exploiting this potentially game-changing technology. Currently, there are no comprehensive publications on patient-relevant future healthcare digital twin research and development opportunities, and many areas remain largely unexplored. This could provide obvious low-hanging fruit. In time, and considering all the exploitable advantages outlined, digital twin healthcare systems could evolve personalized medicine on a larger scale. On a global canvas, they could extend and provide basic healthcare in resource-poor countries where access to doctors is extremely limited. Instead of using digital twins as reactive to existing disease symptoms or pre-pathology signs, digital twins could predict disease ways before the fact. Proactive technologies can save health services time and money by efficiently prioritizing resources for the treatment of citizens who have serious issues that require immediate care [15, 16].

CONCLUSION

Digital twins represent a groundbreaking advancement in healthcare, enabling highly personalized treatment plans that account for individual physiology, preferences, and genetic predispositions. By integrating real-time data and leveraging advanced computational technologies, digital twins facilitate predictive modeling and informed decision-making, thus improving patient outcomes and satisfaction. However, their successful implementation requires robust technological infrastructure, interdisciplinary collaboration, and stringent ethical frameworks to address data privacy and algorithmic biases. Future advancements in AI, machine learning, and big data analytics are poised to further enhance the capabilities of digital twins, expanding their impact across diverse healthcare settings. As this technology matures, it holds the promise of transforming global healthcare delivery, from addressing resource limitations in underserved regions to pioneering proactive and preventive health interventions. By navigating current challenges and capitalizing on emerging opportunities, digital twins could redefine the future of personalized medicine.

REFERENCES

1. Kaul R, Ossai C, Forkan AR, Jayaraman PP, Zelcer J, Vaughan S, Wickramasinghe N. The role of AI for developing digital twins in healthcare: The case of cancer care. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery. 2023 Jan;13(1):e1480. wiley.com
2. Ahmed I, Ahmad M, Jeon G. Integrating digital twins and deep learning for medical image analysis in the era of COVID-19. Virtual Reality & Intelligent Hardware. 2022 Aug 1;4(4):292-305.
3. Wang W, Guo H, Li X, Tang S, Li Y, Xie L, Lv Z. BIM information integration based VR modeling in digital twins in industry 5.0. Journal of Industrial Information Integration. 2022 Jul 1;28:100351. [HTML]
4. Liu M, Fang S, Dong H, Xu C. Review of digital twin about concepts, technologies, and industrial applications. Journal of manufacturing systems. 2021 Jan 1;58:346-61.
5. Li YH, Li YL, Wei MY, Li GY. Innovation and challenges of artificial intelligence technology in personalized healthcare. Scientific reports. 2024 Aug 16;14(1):18994.
6. Alghamdi MA, Fallica AN, Virzì N, Kesharwani P, Pittalà V, Greish K. The promise of nanotechnology in personalized medicine. Journal of personalized medicine. 2022 Apr 22;12(5):673. mdpi.com
7. Chen J, Yi C, Okegbile SD, Cai J, Shen X. Networking architecture and key supporting technologies for human digital twin in personalized healthcare: A comprehensive survey. IEEE Communications Surveys & Tutorials. 2023 Sep 4;26(1):706-46. [PDF]

8. Mihai S, Yaqoob M, Hung DV, Davis W, Towakel P, Raza M, Karamanoglu M, Barn B, Shetve D, Prasad RV, Venkataraman H. Digital twins: A survey on enabling technologies, challenges, trends and future prospects. IEEE Communications Surveys & Tutorials. 2022 Sep 22;24(4):2255-91. mdx.ac.uk
9. Elayan H, Aloqaily M, Guizani M. Digital twin for intelligent context-aware IoT healthcare systems. IEEE Internet of Things Journal. 2021 Jan 12;8(23):16749-57. [HTML]
10. Botín-Sanabria DM, Mihaita AS, Peimbert-García RE, Ramírez-Moreno MA, Ramírez-Mendoza RA, Lozoya-Santos JD. Digital twin technology challenges and applications: A comprehensive review. Remote Sensing. 2022 Mar 9;14(6):1335. mdpi.com
11. Villalonga A, Negri E, Biscardo G, Castano F, Haber RE, Fumagalli L, Macchi M. A decision-making framework for dynamic scheduling of cyber-physical production systems based on digital twins. Annual Reviews in Control. 2021 Jan 1;51:357-73. sciencedirect.com
12. Hribernik K, Cabri G, Mandreoli F, Mentzas G. Autonomous, context-aware, adaptive Digital Twins—State of the art and roadmap. Computers in Industry. 2021 Dec 1;133:103508.
13. Sun T, He X, Li Z. Digital twin in healthcare: Recent updates and challenges. Digital Health. 2023 Jan;9:20552076221149651.
14. Sun T, He X, Song X, Shu L, Li Z. The digital twin in medicine: a key to the future of healthcare?. Frontiers in Medicine. 2022 Jul 14;9:907066.
15. Okegbile SD, Cai J, Niyato D, Yi C. Human digital twin for personalized healthcare: Vision, architecture and future directions. IEEE network. 2022 Jul 25;37(2):262-9.
16. Subasi A, Subasi ME. Digital twins in healthcare and biomedicine. InArtificial Intelligence, Big Data, Blockchain and 5G for the Digital Transformation of the Healthcare Industry 2024 Jan 1 (pp. 365-401). Academic Press. [HTML]

CITE AS: Kibibi Muthoni L. (2025). The Role of Digital Twins in Personalizing Patient Treatment Plans in Healthcare. RESEARCH INVENTION JOURNAL OF BIOLOGICAL AND APPLIED SCIENCES 5(1):67-70. https://doi.org/10.59298/RIJBAS/2025/516770